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WADC TECHNICAL REPORT 52-259

THE EFFECT OF DURATION OF LIGHT ADAPTATION ON TIME REQUIRED FOR DETECTION OF A TARGET ON A SIMULATED PPI SCOPE

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DECEMBER 1952

WRIGHT AIR DEVELOPMENT CENTER

AF-WP-(B)-O-25 JUN 53 250

FOREWORD

This report was prepared by Columbia University under USAF Contract No. AF 33(038)-22616 covering work on Visual Factors in Cathode Ray Tube Data Presentation. The contract was initiated under a project identified by Research and Development Order No. 694-45, Presentation of Data on Radar Scopes, and was administered by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with Dr. Kenneth T. Brown acting as Project Engineer.

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INTRODUCTION

The purpose of the present experiment is to determine the effect of duration of light adaptation to a high luminance level on the time required to detect a target on a PPI type cathode-ray tube display. In many situations where such equipment is used, exposure of the operator to high luminances cannot be avoided. It therefore becomes important to determine visual display conditions which will minimize the effects of light adaptation on detection time or some other measure of operating performance.

There have been a number of studies of the effects of light adaptation on light detection and light discrimination thresholds. The results of these studies afford valuable information from which qualitative effects of light adaptation on cathode ray scope viewing can be predicted.

The dark adaptation experiments of Haig (3), Hecht, Haig and Chase (6), Wald and Clark (10), and Mote and Riopelle (7), all present data in the form of families of curves relating threshold luminance to time in the dark for various conditions of light adaptation. An estimate of dark adaptation time required for the detection of stimulus patterns of selected luminances as a function of light adaptation can readily be obtained from such curves (3).

Simonson, Blankstein, and Carey (8) made direct determinations of dark adaptation time required for the detection of a small test patch of low luminance at various levels and durations of light adaptation. The usefulness of their results is somewhat limited by the fact that they did not use exposure durations long enough to adapt the eye to a steady state.

In a PPI scope presentation, the visual function required is probably more often the discrimination of differences in luminance than the simple detection of light. Blackwell (1) has published data relating adaptation luminance, area of test presentation, and the threshold luminance for detection of a test presentation against the adaptation field. These data may find considerable application in the solution of practical problems involving these parameters. In most of the experimental work on the discrimination of luminance differences, the thresholds determined have been those for the detection of a test pattern against a background luminance to which the eye has been adapted. This is a serious limitation when it is desired to generalize results to problems involving the effect of adaptation on cathode-ray scope viewing. A complete analysis of these problems requires information regarding instantaneous or early threshold target luminances for scope background luminances which are in many cases much lower than those luminances to which the eye has been adapted. Craik (2) has performed an experiment in which discrimination thresholds were determined for eight test background luminances with prior adaptation to a number of different luminances for each background condition. In general, thresholds were found to be at a minimum when test background and adaptation luminances were equal. The implication for scope viewing is that optimally, observers should be adapted to a luminance level of the same order as the luminance of the scope background.

The unique character of a PPI scope presentation renders it impossible to make accurate quantitative predictions of the effects of adaptation on target detection from the results of experiments such as those cited above. The determination of optimal operating conditions for cathode ray scope displays requires extensive research using the actual displays themselves. Only under these conditions can the effects of phosphor decay characteristics, scanning rate, and other parameters be determined.

An extensive experimental program on the visibility of cathode ray tube screens has been undertaken at Johns Hopkins University. Relevant to the present investigation is an experiment on the effect of light adaptation by Hanes and Williams (4). These authors have investigated the dependence of threshold target conditions and detection times for specific target conditions on duration and luminance of light adaptation. Their results are in agreement with those of Craik in indicating that differential brightness sensitivity is greatest when test and adapting illuminations are equal. Immediately relevant to the present experiment are functions relating detection time to duration of light adaptation at a luminance of 2000 millilamberts. Four curves are presented representing different combinations of target and background luminance. Increase in duration of light adaptation results in an increase to a maximum detection time for three of the combinations but has no effect on detection time for the fourth combination. Target and background luminances were not varied independently and systematically.

In the present experiment, time required to detect a target on a simulated PPI scope is determined for several different target luminances at each of four background luminances. Light adaptation is at a luminance of 3100 millilamberts, and durations of 5, 15, 30, 60, and 120 seconds are used.

APPARATUS

A. General

The apparatus used in the present experiment is a simulated PPI presentation which involves no electronic components.

A circular transparency which duplicates the decay characteristic of the type of phosphorescent coating to be investigated is carried by an annulus, which in turn is supported by four bearings equally spaced around its circumference. The density gradient of the transparency is such that the luminance of a given point past which it is rotated decreases with respect to time in the same manner as the luminance of a phosphor after excitation. The transparency was made by a photographic technique described below. The annulus is rotated at different speeds by a synchronous motor through a system of change gears and a final friction drive to its circumference. The spectral characteristic of the phosphor (P-7) is duplicated as closely as possible by the use of an appropriate Wratten color filter. Variations in overall brightness of the presentation are obtained with polaroids and neutral density filters. A wide range of contrasts between the "target" and background is achieved by using a small piece of cellophane cut in the desired shape to represent the target. This is located between the polarizer and the analyzer. Being anisotropic, it effectively rotates the plane of polarization of light coming from the polarizer. Variations of luminance of the target and background are obtainable independently by appropriate changes in the relative orientations of the optical axis of the cellophane and the axes of polarization of polarizer and analyzer. Illumination is provided by a 100 watt frosted tungsten bulb behind an opal glass diffusing screen.

After an initial consideration of the problems which were to be investigated, it was decided that several important advantages favored the use of such equipment over electronic equipment. Many problems of measurement and specification are avoided since photometric measurements can be made directly over the entire range to be investigated with the present apparatus. It is, therefore, unnecessary to base any of the luminances on extrapolation of empirical relations between electrical and photometric variables. It is recognized, of course, that although presentations used in the present study can be specified more accurately, they might not conform as closely with the actual situation. However, the advantages of accurate specification for an understanding of the basic problems involved and a possible theoretical interpretation of results are considered to be of primary importance. It should also be mentioned that in an experimental study of this type the use of equipment which is presumably identical in every important respect with equipment used in actual practice does not guarantee that presentations obtained are directly comparable, owing to the variability between cathode ray scopes and other electronic components of the same type and the variability in individual components with their continued use.

Another important advantage inherent in the present apparatus is the fact that the range of variation of the relevant variables is greater, and they can be varied with a greater degree of independence than would be possible if electrical elements and the characteristics of phosphorescent coatings imposed limitations. For this reason optimal conditions not presently obtainable in electronic equipment may be identified which will enable better direction of future developments in this area.

B. Details of Construction

1. Characteristics of the P-7 coating.

a. Spectral Distribution. Scopes used in PPI presentations commonly have coatings which afford relatively long persistence. These coatings are of the cascade type, and have more than one layer of phosphorescent material. In the present experiment it is desired to approximate conditions obtaining with the P-7 coating. This consists of a blue fluorescing layer of silver activated zinc sulfide and a long persistence copper-activated zinc sulfide-cadmium sulfide yellow-emitting phosphor with 15 percent cadmium sulfide. Electrons striking the first layer cause it to fluoresce very briefly and this fluorescence excites the persistent phosphor located next to the glass. The initial flash has a peak at about 440 mu, while the peak of yellow persistence is at about 560 mu.

It would have been possible to place a blue filter behind the narrow minimum density "trace" portion of the transparency described below in order to duplicate the initial blue flash, but this was not done in the present experiment.

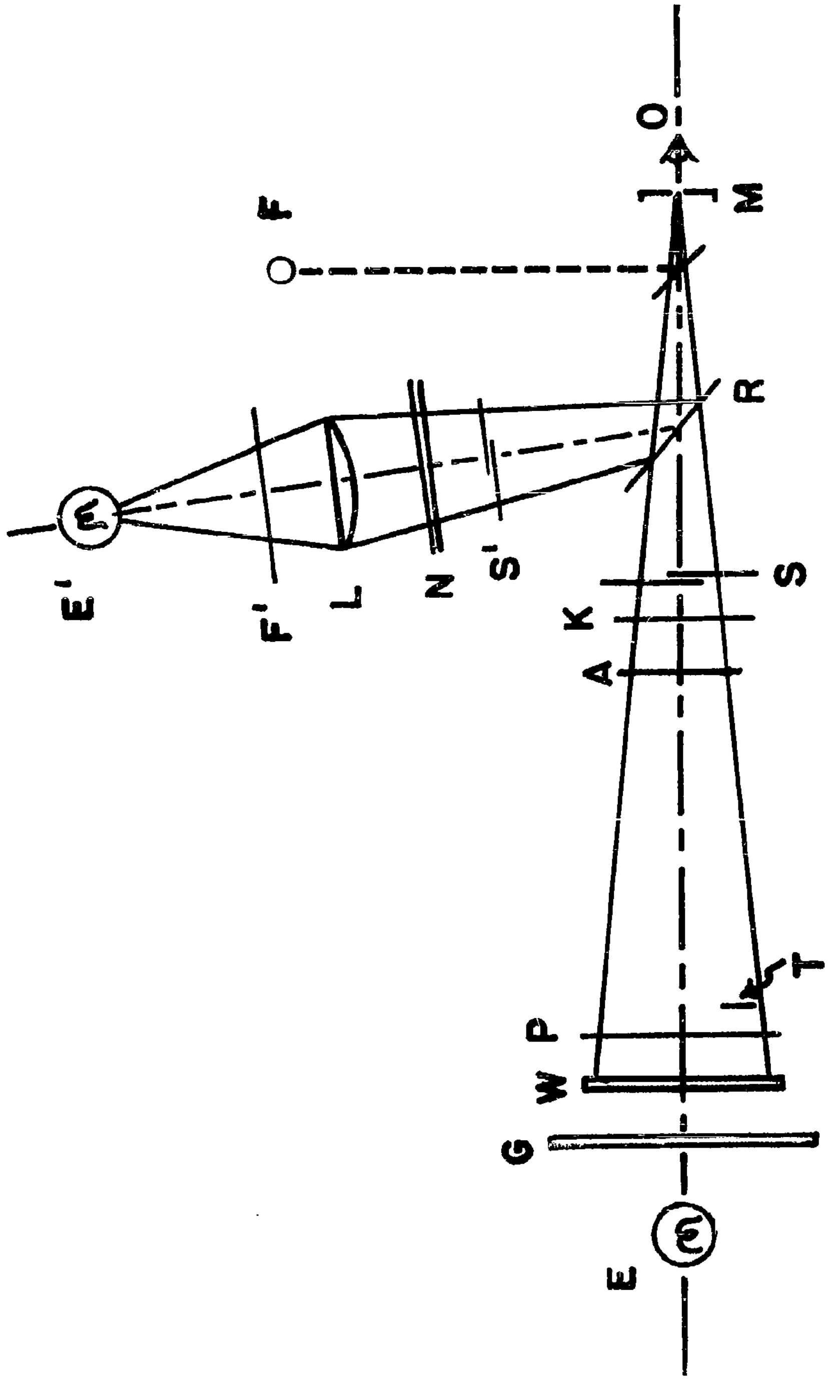

Figure 1: Schematic Diagram of the Apparatus
See text for an explanation of symbols.

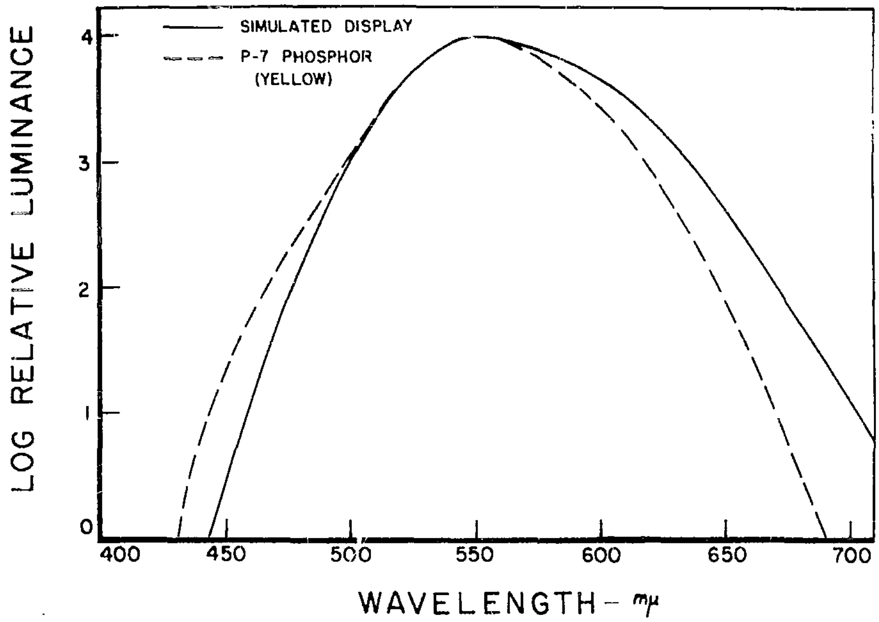

Figure 2: Comparison of the spectral characteristic of the P-7 phosphor (9, p. 646) with the spectral distribution of the simulated presentation as measured with a Beckman Spectrophotometer.

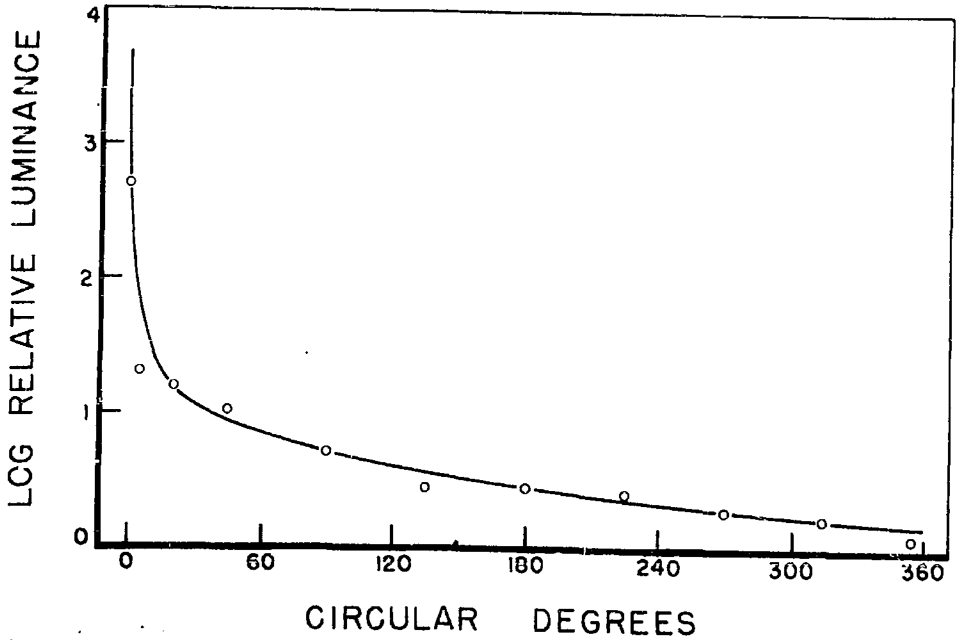

Figure 3: Comparison of the decay characteristic of the P-7 phosphor with the simulated decay function. The plotted points represent the luminance of the simulated display; the smooth curve represents an equation for the P-7 phosphor decay function.

The yellow persistence is duplicated in the following manner. A distribution of relative spectral power of the radiance from the yellow phosphor was multiplied by the I.C.I. luminosity function. To permit comparison with filter densities the resulting distribution was replotted in terms of the logarithms of reciprocals of the ordinate points. Several color filters and filter combinations were selected having maximum transmissions at about 560 mu and their spectral distribution characteristics were also multiplied by the I.C.I. luminosity function. In addition, they were multiplied by the relative energy emitted in the visible range from a tungsten lamp at a color temperature of 2800°K. It was also necessary to correct for the spectral transmission characteristics of the reflector R (See Figure 1) and the polaroid and cellophane combination. The resulting distributions were plotted in terms of density versus wavelength on the same graph as the phosphor distribution, arbitrarily positioning points of minimum density with respect to the ordinate scale such that they were at the same ordinate value as the minimum logarithmic value of the transformed curve representing the phosphor. The spectral characteristic of an Eastman K102 Wratten filter is reasonably close to that of the phosphor, so the K102 (K in Figure 1) was selected for use in the experiment. A comparative plot of relative spectral luminance from the simulated display and from the P-7 phosphor is presented in Figure 2.

d. <u>Decay Characteristic</u>. Data published by Williams and Bartlett (11) on the decay of a P-7 screen for different bias voltages seems to indicate that the decay functions are roughly parallel up to at least six seconds of decay over a fairly wide range of bias voltages. The range of log luminance at any given time after excitation corresponding to this range of bias voltages is more than 1.5. The effective limits of log luminance at any instant after excitation are determined by threshold of the eye and saturation of the phosphor. The maximum range is probably not much greater than 1.5.

Data for nine volts bias were taken as representative and replotted in terms of log luminance versus circular degrees for three scanning rates, 60, 20, and 10 RPM. For a given scanning rate in degrees per second, each value of circular degrees on the abscissa represents a specific time after excitation. A plot of phosphorescence level in centibels for the P-7 phosphor versus log time after excitation in seconds, published in Soller, Starr, and Valley (9), was fitted by a straight line, the equation for which was transformed into another equation yielding log luminance in millilamberts as a function of circular degrees, with scanning rate as a parameter. By a simple transposition on the ordinate axis, this equation provided a very good fit to the data of Williams and Bartlett. This seemed to indicate that as a first approximation, the assumption was justified that variation of the electrical parameters would yield parallel decay curves, at least over the ranges investigated. It was, therefore, decided to duplicate the decay function of the P-7 screen on a photographic film transparency similar to a circular wedge, since one such wedge, having the appropriate gradient of density for a given scanning rate, could be used over a wide range of luminances.

A circular piece of photographic paper was exposed using a masking device rotated at a constant speed about the center of the paper which gradually uncovered its entire surface. Negatives were made from the paper, and transparencies with the desired gradient obtained from these negatives by appropriately controlling exposure duration, strength and temperature of developer, and time of development. Density gradients were measured using an Eastman Densitometer.

Since the range of density which can be obtained on photographic film is somewhat less than that necessary to duplicate the decay function, the required density gradient was matched as closely as possible for all but the initial part. Initial energy levels could then be matched by increasing the duration of maximum luminance in the simulated presentation within critical duration. A gradient representative in form of conditions with a 60 RPM scanning rate for all but the first three or four degrees was made on a photographic transparency by the method outlined above. The empirical equation used to fit decay data was integrated over time, yielding an expression for total energy emitted from any point on the scope during any time of decay as a function of decay time. The density range of the gradient which had been made is equal to 2.60. This represents the difference in log luminance between the initial flash, and the luminance after one second of decay which this particular transparency affords with a 60 RPM scanning rate. Desired log luminance at one second decay was calculated, and added to 2.60. The antilog of this value corresponds to the maximum luminance obtainable initially with conditions which would provide the correct luminance at the point representing one second decay. From the integrated expression mentioned above and the maximum obtainable luminance, a time value was calculated. This time represents the time during which maximum luminance should be transmitted by the transparency in order to equate energy in the simulated presentation with energy as calculated for an actual presentation for the same time. It is well within critical duration. Converted to circular degrees, this time represents approximately one degree on the gradient. Accordingly, the portion of the transparency from which the emulsion was removed was made one degree in width. A comparative plot of relative luminance from the prepared gradient and from a P-7 phosphor as a function of circular degrees for a 60 RPM scanning rate is presented in Figure 3.

2. Target presentation and light adaptation.

a. The targets appearing on intensity modulated PPI scopes consist of short arc segments brighter than the background, located at distances from the scope center corresponding to the ranges of objects which they represent. Signals reflected from an object serve to decrease negative bias at a point in the time cycle such that excitation on the scope face is increased at a point corresponding to the actual position of the object in range and bearing.

The target presentation in the present experiment consists of an arc segment or "pip," the center of which is located at a bearing of 260° clockwise relative to the top of the circular scope face. This pattern is at a distance of 13 1/8 inches from the exit pupil. The pip is at a distance of 7/8 inch from the center of the 4 3/4 inch scope face. It thus stimulates the retina at 3°50' from the fovea when fixation is maintained at the center of the scope. The length of the arc on the scope is 46° 28' and subtends a visual angle of approximately 3°16'. The radial thickness of the arc line is 1/32 inch, or 8 minutes at the retina.

The target consists of a thin piece of cellophane approximately .001 inch thick, cut in the appropriate shape and held between two circular pieces of glass. The position of the target, T, relative to the other elements of the apparatus is indicated in Figure 1. Between the rotating annulus containing the decay wedge W and the target is a polaroid P also held between two pieces of glass. Light coming from the source E passes through the opal glass diffusing screen G, through the decay wedge, and through the polarizer before passing through the glass holding the cellophane target. The effect of the cellophane is to rotate the plane of polarization of that portion of the light which passes through it. In consequence, an observer at O looking through the second polaroid A sees the target at a higher luminance than the background, the exact luminance difference depending on the relative orientations of the two polaroids and the optical axis of the cellophane. The background luminance is set by the angular separation θ between the axes of the two polaroids. The target luminance is set by the angular separation α of the optical axis of the cellophane from whichever polaroid axis is nearest. In the present experiment all settings were made such that α was measured relative to the axis of P. The angular rotation of the plane of polarization of light passing through the cellophane is equal to 2α and is in the direction of the axis of A.

To the eye of the observer at O, the test field appears as a dark circular pattern with a small red fixation spot at the center which is reflected in from F. The target appears to be periodically illuminated as the trace line rotates past it. The trace line appears as a radial line which rotates about the red fixation spot. Under conditions of low background luminance, the trace line may not be visible to the observer. Scanning rate, or rate of rotation of the trace line, was held constant at 60 RPM in the present experiment.

b. Light adaptation is provided by a 150 watt tungsten lamp E' at a distance of 6 3/4 inches from lens L. Lens L has a focal length of 4 1/4 inches, is 4 1/8 inches in diameter, and is located at an optical distance of 11.5 inches from the 3 mm exit pupil M. That portion of the light from L which is reflected by R is therefore converged at the exit pupil. To the eye of an observer at M, lens L thus appears filled with light and provides a light adaptation field 20°20' in diameter. Fixation during light adaptation is provided by a black dot F' on a piece of plain glass two inches behind lens L. Level of light adaptation may be varied by placing appropriate filters at N.

Onset and termination of exposure of the light adapting field and of the test presentation are controlled by the shutters S' and S respectively.

3. Calibration and measurement.

The light adaptation field was calibrated, using a binocular matching technique. An observer viewed the light adaptation field with the right eye and the field of the matching standard with the left eye. Luminance of the light adaptation field was adjusted by the experimenter, who manipulated a pair of polaroids at N. The method of limits was used. The maximum luminance of the light adaptation field with the 150 watt bulb operated on 125 volts d.c. was thus determined to be 8500 millilamberts. In the present experiment a .44 density filter was placed at N providing a light adaptation luminance of 3100 millilamberts.

Maximum luminance obtainable on the simulated scope was determined by measurement with a Macbeth Illuminometer. The exit pupil was removed, and the measurement made through all elements of the system except the circular wedge. Minimum density of the wedge was measured on an Eastman Densitometer. The luminance value thus determined after correcting for wedge density is 43.6 millilamberts.

The cellophane and polaroid combination was calibrated by means of luminance measurements using a Macbeth illuminometer. The two polaroids with a piece of cellophane between them were mounted over a piece of opal glass which was illuminated by a frosted bulb. A scale enabled accurate setting of the angular relations of the axes of the polaroids and the axis of the cellophane. Measurements were made for seven settings of the polaroids from zero to 90 degrees at intervals of 15 degrees. For each setting of the polaroids, measurements were made with the cellophane at five degree intervals from a position where its axis was in line with one of the polaroids to a position where its axis was in line with the other polaroid. The difference between the density through the cellophane and the minimum density through the two polaroids with their axes in line is accurately described by the expression $-2 \log \cos (\theta - 2\alpha)$ for all values of $(\theta - 2\alpha)$ less than 75 degrees.

PROCEDURE

Five durations of light adaptation were used in the present experiment, 5, 15, 30, 60, and 120 seconds, all at a level of 3100 millilamberts. Fourteen different combinations of target and background luminance which were used are presented in Tables 1, 2, 3, and 4.

At the beginning of each experimental session, subjects were dark adapted for a period of three minutes. Ten seconds before the end of the three minute period, following a signal by the experimenter, the subject adjusted to a chin rest and fixated the red fixation spot with the right eye. Precisely at the end of the three minute period the experimenter pressed a key turning on the adapting light and opening shutter S' by means of a solenoid. Light adaptation duration for the initial determination was always 120 seconds. As soon as the light adaptation field was presented, the subject pressed a key in the dark room which was in series with a second solenoid connected to shutter S. The solenoid circuit was not closed, however, until the experimenter released his key at the end of the light adaptation period. With the release of the experimenter's key, shutter S' closed and the adapting light turned off. At the same time the second solenoid opened shutter S, exposing the scope presentation and simultaneously closing a switch which started a chronoscope. The subject maintained fixation on the red fixation spot until he was able to see the target, then released his key, closing shutter S and stopping the chronoscope.

The experimenter recorded the target detection time and set the chronoscope back to zero. The next presentation of the adapting light followed detection of the target after an interval of 90 seconds. In each experimental session, 25 detection time determinations were made. Five different target presentation conditions were included in each session, and detection times for each of the five light adaptation durations were determined for each condition. The five determinations for a given condition were made in sequence, but the order of durations of light adaptation was varied for different conditions. There were fourteen such experimental sessions for each subject.

The interval between individual determinations was selected on the basis of preliminary data which indicated that for intervals of 90 seconds or more, the order of light adaptation durations did not significantly affect mean detection times with a given condition of target luminance. Data were obtained for two male observers, both of whom were nearly emmetropic and anastigmatic. All observations were made using the right eye.

RESULTS

The median detection times for the different experimental conditions and the range of detection times for each condition are given in Tables 1, 2, 3, and 4. Each table includes all the data for a single background luminance. These data are based on five determinations following each of five durations of adaptation to the standard adapting field of 3100 millilamberts for each condition of the test presentation. The effects of light adaptation duration, target luminance, background luminance, and contrast between target and background on detection time are presented graphically in Figures 4, 5, 6 and 7.

Median target detection time as a function of the duration of light adaptation is shown in Figure 4. Separate sets of curves are plotted for each observer. A family of curves with target luminance as the parameter is presented for each of the four background luminances investigated. It will be noted that the range of target luminances investigated is decreased as the level of background luminance approaches the maximum luminance obtainable with the particular light source being used. In view of the variability of the data, no attempt was made to fit smooth curves to the experimental points.

In general, detection time increases with increase in light adaptation duration. It may be assumed that asymptotic values of detection time would be reached after durations of light adaptation long enough to bring the eye to a steady state (5).

TABLE 1

Median and range of detection time in seconds after light adaptation to 3100 millilamberts for five durations and for five levels of target luminance, with log background luminance at -0.22 millilamberts. Subjects JB and HR.

Log Tgt. Lum. (ml)		Target detection time for log background luminance = -0.22 millilamberts									
		Adaptation time - Seconds									
		5		15		30		60		120	
		JB	HR	JB	HR	JB	HR	JB	HR	JB	HR
1.64	Median	3.00	2.30	5.98	4.10	15.81	6.12	21.56	22.59	24.52	34.49
	Range	2.50 to 3.64	1.96 to 3.71	4.15 to 6.48	3.96 to 8.54	10.23 to 20.65	2.41 to 11.02	19.99 to 22.39	10.57 to 34.38	22.31 to 37.82	31.42 to 39.07
1.41	Median	3.66	2.57	6.13	4.85	22.93	8.20	26.27	19.59	29.73	35.22
	Range	3.18 to 4.15	1.67 to 3.53	5.82 to 6.63	2.15 to 5.10	16.88 to 25.03	4.97 to 12.16	25.25 to 36.09	13.49 to 36.70	27.79 to 32.49	29.07 to 39.46
1.04	Median	5.49	3.82	15.76	11.95	37.10	25.05	46.83	30.12	44.44	56.73
	Range	5.03 to 5.69	2.60 to 4.26	13.46 to 18.27	6.31 to 13.40	32.36 to 43.40	13.13 to 32.00	42.63 to 50.73	19.04 to 44.90	43.35 to 59.37	44.67 to 58.94
0.71	Median	7.33	6.47	45.55	17.50	71.71	38.04	88.08	65.79	91.81	84.93
	Range	5.83 to 10.07	5.74 to 12.75	30.72 to 56.80	13.46 to 28.51	65.55 to 102.37	24.43 to 42.50	79.15 to 98.26	48.78 to 72.84	86.16 to 102.56	75.01 to 105.80
0.34	Median	21.83	27.30	73.25	44.06	93.77	73.34	114.66	105.65	117.57	139.83
	Range	16.00 to 25.80	18.79 to 52.72	64.67 to 80.20	23.72 to 62.65	80.88 to 116.30	30.10 to 127.98	91.54 to 131.25	88.70 to 148.55	96.24 to 148.31	133.15 to 179.03

TABLE 2

Median and range of detection time in seconds after light adaptation to 3100 millilamberts for five durations and for four levels of target luminance, with log background luminance at 0.14 millilamberts. Subjects JB and HR.

Target detection time for log background luminance = 0.14 millilamberts

Adaptation time - Seconds

Log Tgt. Lum. (ml)		5 JB	5 HR	15 JB	15 HR	30 JB	30 HR	60 JB	60 HR	120 JB	120 HR
1.64	Median	3.54	2.65	7.90	3.73	19.48	5.70	25.82	15.63	26.19	33.76
	Range	2.77 to 3.71	2.55 to 3.24	5.35 to 12.26	3.42 to 6.92	13.93 to 27.63	4.42 to 5.80	21.06 to 29.40	13.59 to 19.15	22.56 to 31.35	25.89 to 37.66
1.41	Median	3.89	3.20	7.60	4.48	24.55	7.29	31.36	17.80	32.82	33.32
	Range	2.76 to 5.14	2.74 to 4.15	5.52 to 8.51	4.10 to 6.31	17.41 to 25.62	6.58 to 21.27	21.63 to 33.71	14.45 to 39.42	27.39 to 36.64	29.18 to 54.20
1.04	Median	5.92	4.08	16.52	5.27	31.43	13.63	47.38	39.95	48.47	50.42
	Range	4.76 to 7.24	2.52 to 4.78	11.61 to 23.87	4.90 to 8.61	25.09 to 43.56	10.56 to 28.71	43.83 to 50.60	34.30 to 46.16	46.17 to 56.14	49.25 to 65.13
0.71	Median	6.82	7.13	40.94	22.35	64.85	47.73	70.08	76.17	83.28	87.16
	Range	7.16 to 9.56	5.08 to 11.97	28.31 to 42.10	11.08 to 33.33	50.64 to 72.66	30.54 to 61.08	55.49 to 74.86	59.41 to 89.41	65.63 to 91.69	80.19 to 116.02

TABLE 3

Median and range of detection time in seconds after light adaptation to 3100 millilamberts for five durations and for three levels of target luminance, with log background luminance at 0.71 millilamberts. Subjects JB and HR.

Log Tgt. Lum. (ml)		Target detection time for log background luminance = 0.71 millilamberts									
		Adaptation time - Seconds									
		5		15		30		60		120	
		JB	HR	JB	HR	JB	HR	JB	HR	JB	HR
1.64	Median	2.84	2.45	6.81	3.89	14.86	6.78	22.07	15.25	28.95	44.75
	Range	1.85 to 3.77	1.84 to 2.51	6.46 to 7.31	2.84 to 7.84	13.97 to 24.24	4.61 to 9.38	17.84 to 32.55	11.85 to 33.54	23.15 to 29.64	22.52 to 49.74
1.41	Median	3.93	2.49	8.86	4.81	35.41	10.32	38.56	28.55	45.84	40.20
	Range	2.93 to 5.18	1.76 to 2.95	8.35 to 11.56	3.88 to 5.21	15.94 to 44.42	7.35 to 12.73	36.09 to 56.28	18.07 to 39.61	35.35 to 67.21	29.53 to 46.12
1.04	Median	6.45	6.35	23.57	15.85	46.02	35.40	63.56	63.17	69.96	84.74
	Range	5.45 to 10.53	6.00 to 13.13	11.18 to 38.81	13.78 to 23.64	31.55 to 61.44	24.99 to 50.14	43.63 to 67.22	41.65 to 74.73	58.64 to 75.48	82.65 to 98.97

TABLE 4

Median and range of detection time in seconds after light adaptation to 3100 millilamberts for five durations and for two levels of target luminance, with log background luminance at 1.26 millilamberts. Subjects JB and HR.

Log Tgt. Lum. (ml)		Target detection time for log background luminance = 1.26 millilamberts									
		Adaptation time - Seconds									
		5		15		30		60		120	
		JB	HR	JB	HR	JB	HR	JB	HR	JB	HR
1.64	Median	4.14	4.19	9.09	8.09	23.15	12.01	34.13	44.82	39.52	55.80
	Range	2.39 to 4.49	2.76 to 7.24	7.62 to 10.42	6.54 to 20.86	20.22 to 31.90	7.57 to 19.43	29.82 to 37.12	20.48 to 60.83	38.53 to 40.92	48.53 to 57.45
1.41	Median	13.05	19.99	41.64	51.27	69.10	57.82	86.02	62.08	88.97	93.59
	Range	12.69 to 15.25	13.41 to 44.87	40.66 to 60.66	32.14 to 56.85	56.97 to 88.48	27.01 to 74.24	78.06 to 106.52	57.25 to 92.07	83.22 to 117.60	84.04 to 138.31

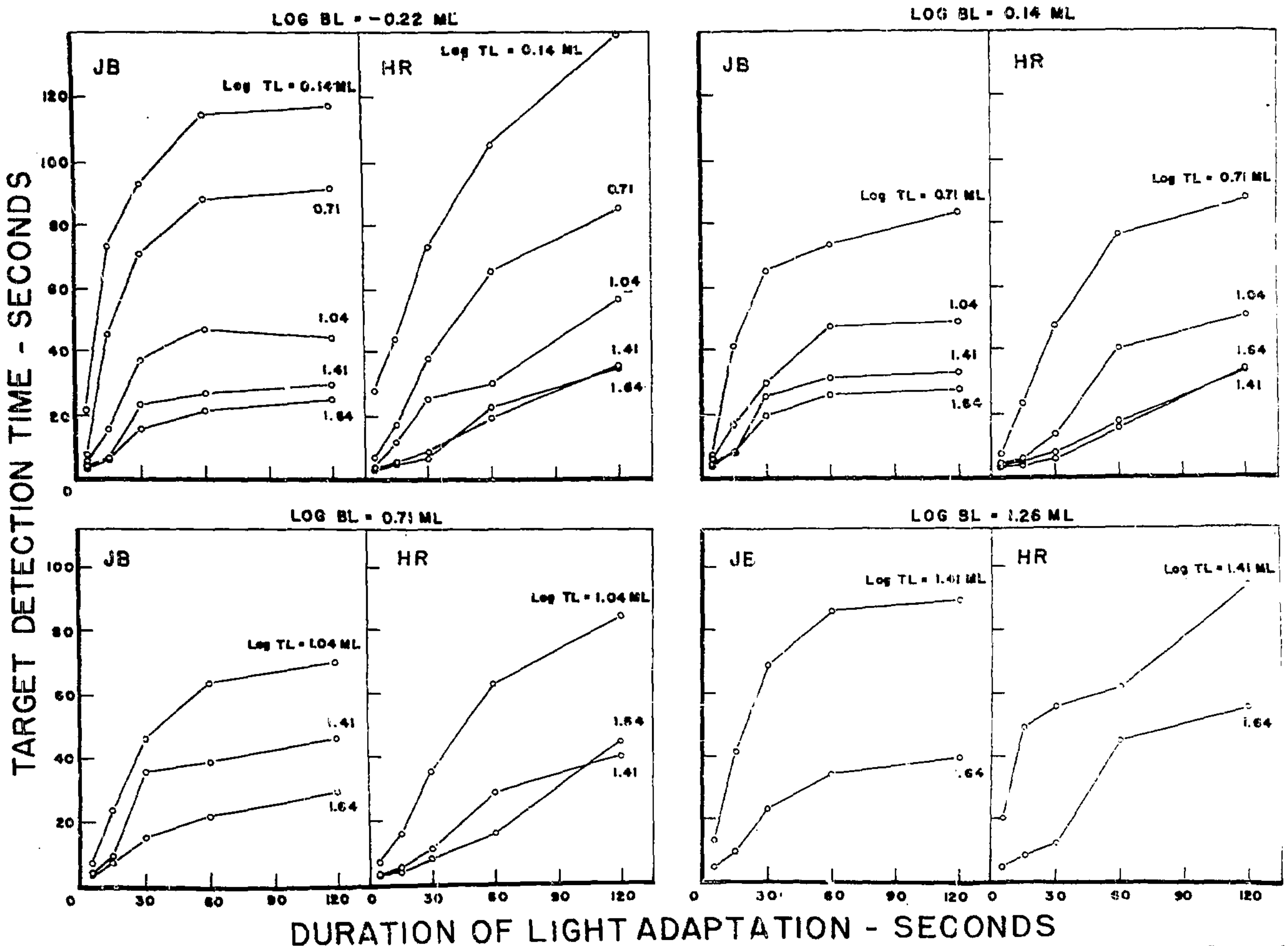

Figure 4: Target detection times for different target and background luminances as a function of duration of adaptation to a luminance of 3100 millilamberts. The number at the top of each set of curves refers to log background luminance. The number at the last datum point of each curve refers to log target luminance. Data for subjects JB and HR.

The effect of increasing target luminance at a given background luminance is to decrease detection time (Figure 5). The actual change in detection time resulting after a change from one specific value of target luminance to another depends on the level of background luminance and the conditions of prior light adaptation. The effectiveness of a given amount of increase in target luminance for decreasing detection time diminishes with increase in the differential between initial target and background luminance.

Increasing target luminance also results in a change in the form of the relation between light adaptation duration and detection time (Figure 4). Curves for the higher target luminances are sigmoid, showing initial positively accelerated branches. Curves for lower target luminances are simple negatively accelerated increasing functions of light adaptation duration. Positively accelerated branches result when the target luminance is increased to such a degree that detection time approaches a limiting minimum value for short durations of light adaptation. As detection time approaches a minimum value it ceases to afford a criterion of differences in target luminance and is less sensitive to differences in light adaptation.

In comparing the results obtained for observers JB and HR, it appears that light adaptation is more rapid for JB. At each of the four background luminances, detection times for JB increase relatively very little between 60 and 120 seconds of light adaptation, while for HR there is in most cases a considerable increase in detection time between 60 and 120 seconds of light adaptation. From the results of JB, it would appear that the duration of light adaptation at which a maximum detection time is reached is independent of target luminance. The functions relating detection time to light adaptation duration for JB are more regular than those for HR. This latter difference may be attributed, at least in part, to the fact that JB is more experienced as an observer than HR.

The effect of increasing background luminance on detection time may be determined by comparing the curves obtained at different background luminances for a given target luminance. To facilitate such a comparison, the data of Figure 4 have been replotted in Figure 6. In this figure, detection time is expressed as a function of background luminance, with duration of light adaptation as a parameter. Separate graphs are presented for the two observers, and at each of four values of target luminance. From Figure 6 it appears that in most cases detection time increases at an increasing rate with an increase in background luminance. Presumably, as background luminance approaches the value of target luminance, detection time approaches infinity. It may be inferred from Figure 6 that the shorter the duration of light adaptation, the smaller is the allowable ratio between target and background luminance before any extremely rapid increase in detection time occurs. The relation between rate of increase in detection time and target to background luminance ratio also appears to depend upon the absolute value of target luminance. It is not possible to make any estimate of the nature of this dependence from the present data, however.

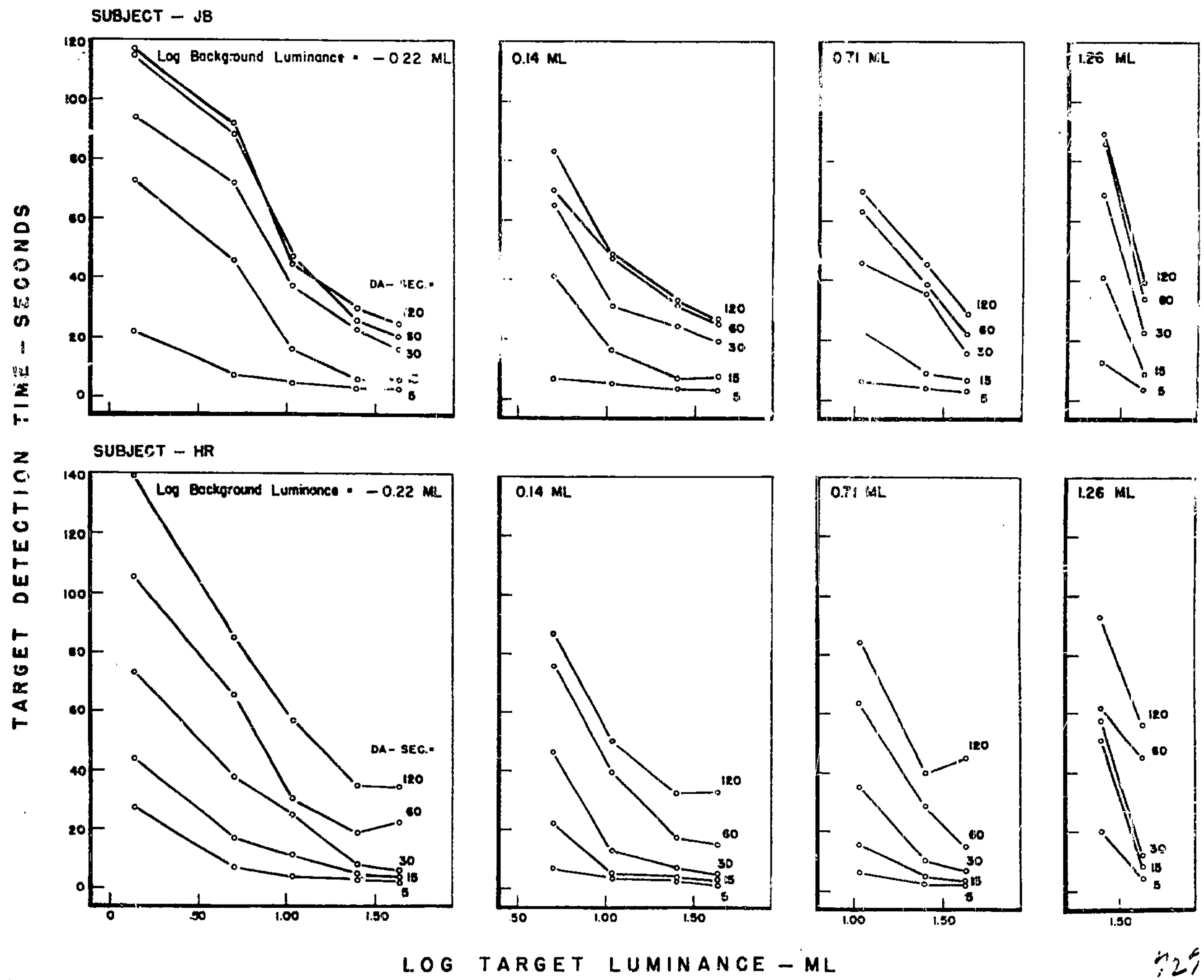

Figure 5: Target detection times for different background luminances and different light adaptation durations as a function of target luminance. The number at the last datum point of each curve refers to the duration of light adaptation in seconds. Data for subjects JB and HR.

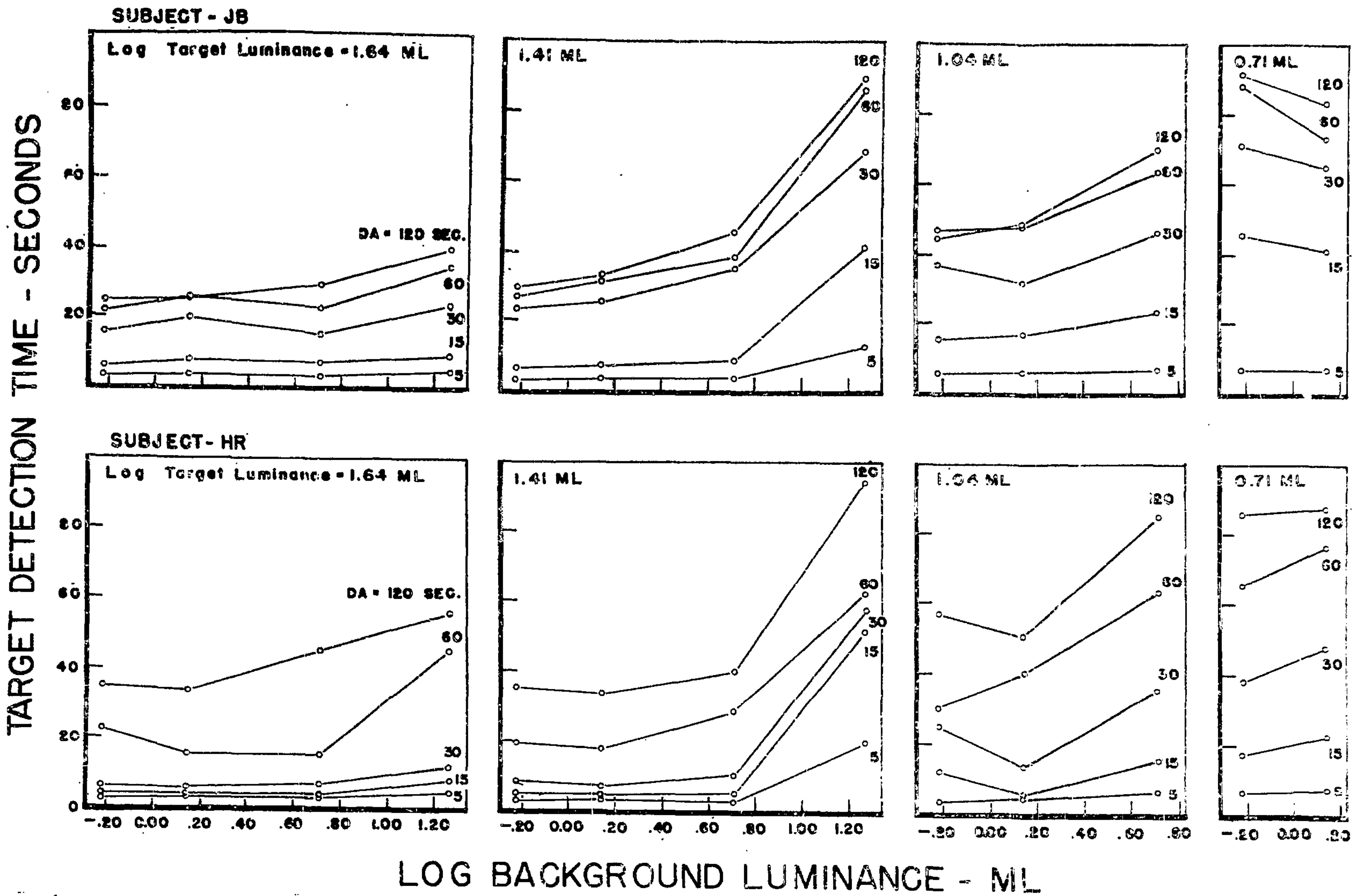

Figure 6: Target detection times for different target luminances and different light adaptation durations as a function of background luminance. The number at the last datum point of each curve refers to the duration of light adaptation in seconds. Data for subjects JB and HR.

One other characteristic of the data in Figure 6 deserves mention. There is a suggestion in results for JB at a target luminance of log 0.71 millilamberts and for HR at a target luminance of log 1.04 millilamberts that within a limited range, under certain conditions, an increase in background luminance (i.e., a decrease in target to background luminance ratio) may result in decreased detection time. Although the present experiment does not afford any definite conclusions on this point, it does indicate the need for a careful investigation of the possibility.

Detection time as a function of contrast is presented graphically in Figure 7. Contrast, $\Delta I/I$, is defined as the ratio of the difference between target and background luminance to background luminance. The plotted points were calculated from data of JB obtained after 120 seconds of light adaptation. This duration was selected as one which would provide the least variable condition of adaptation. Separate curves have been drawn through the data for each of the four background luminances. As the contrast ratio is increased for any level of background luminance, detection time decreases at a decreasing rate. It is probable that detection time would ultimately reach the same minimum value for all four of the curves if higher contrast ratios were obtained for the higher values of background luminance.

Dashed curves have been drawn through data representing equal target luminances in Figure 7. As contrast ratio is increased for the three highest levels of target luminance, detection time decreases at a decreasing rate. It appears that minimum detection time is determined by level of target luminance. For lowered target luminances, minimum detection time is raised and no amount of decrease in background luminance can reduce it further.

The increase in detection time with increased contrast at a target luminance of 0.71 log millilamberts is a reflection of the decrease in detection time with increased background luminance at this target luminance noted in the results of JB in Figure 6. Its significance is questionable.

It is obvious from Figure 7 that predictions about detection time cannot be made from values of contrast alone without further specification of luminance values.

DISCUSSION

The results of the present experiment indicate the nature of the relations of background luminance, target luminance, and duration of adaptation to a high luminance, to the time required to detect a target on a PPI scope. We may consider background luminance to bear a relation to bias voltage, and target luminance to bear a relation to signal strength for any given value of bias voltage. Neither of these relations is linear, however, and target luminance varies with both signal strength and bias voltage in electronic apparatus. The reader is therefore cautioned not to attempt comparison between the curves presented in this report and those appearing elsewhere which are plotted in terms of electrical parameters, without first recognizing the complex nature of the relation between electrical and photometric units.

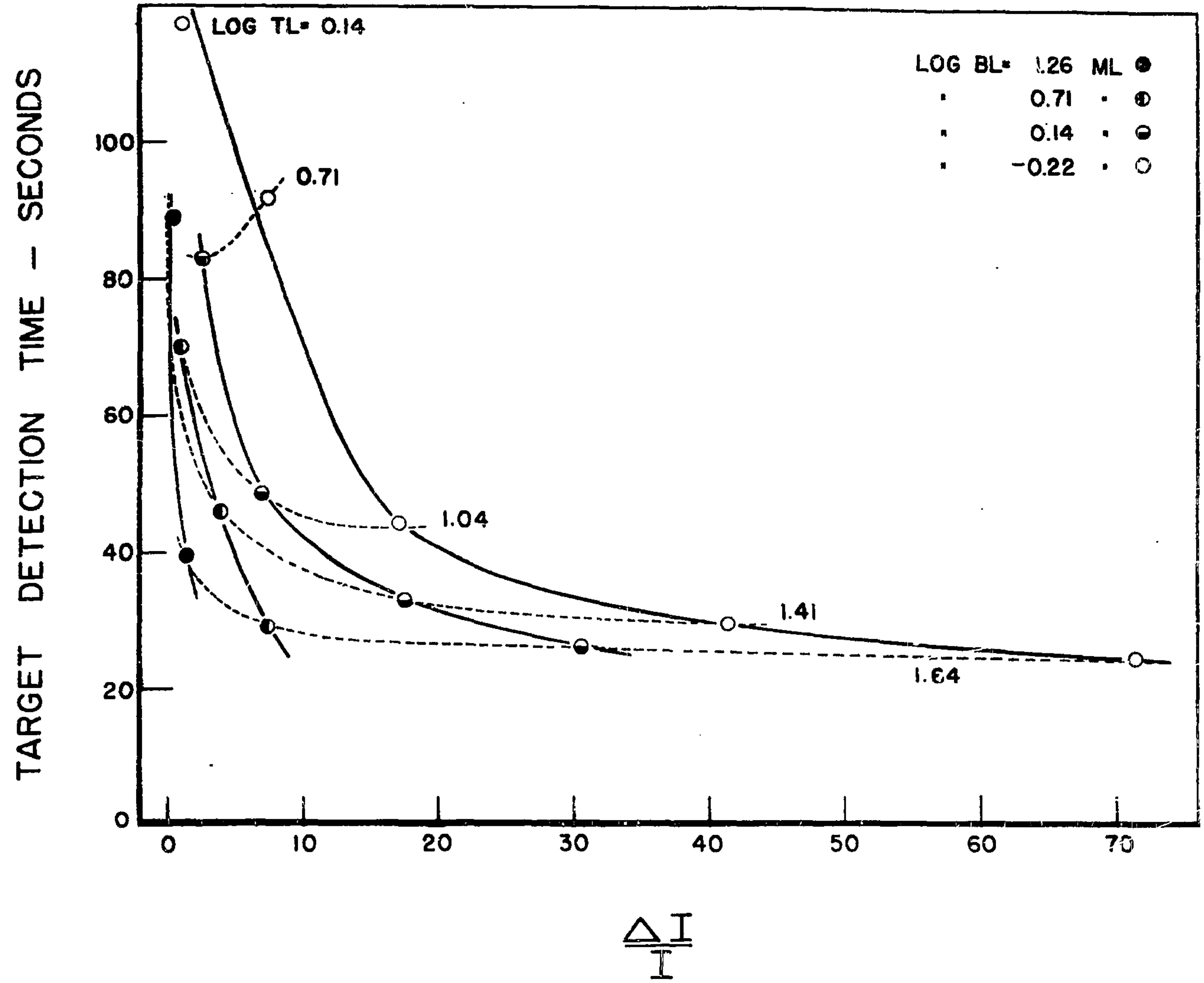

Figure 7: Target detection time as a function of contrast, $\Delta I/I$, for four background luminances (indicated by the coding of the datum points) and for four target luminances (indicated by the numbers beside the dashed curves). Duration of light adaptation was 120 seconds. Data of subject JB.

When a radar operator has been exposed to high luminances and then looks at his scope, a period of time must elapse before he can respond to the presence of a target on the scope. When the adapting luminance is considerably higher than scope luminances, this period of time (target detection time) is found to increase with increased duration of exposure to the adapting luminance. Increase in detection time continues up to an adaptation duration which brings the eye to a steady state of adaptation. In the present experiment, this limiting adaptation duration differed for the two observers. JB had nearly reached steady state adaptation after one minute, while HR had not reached a steady state after two minutes of adaptation. This result is contradictory to that reported by Hanes and Williams (4) who found the same duration of adaptation required for a steady state by all their observers.

In general, minimum detection times are obtained for any given duration of light adaptation with maximum target luminance and minimum background luminance. In terms of the electrical parameters, this means that minimum detection time will probably be achieved with maximum gain and a negative bias voltage that will provide the darkest possible background without appreciable loss in target luminance. Nothing more specific can be said without knowing the exact nature of the dependence of target luminance on bias voltage for a given signal strength and a given amount of gain. The possibility that under certain conditions an optimum value of background luminance may exist, both above which and below which detection time is increased, requires further investigation.

For practical application to radar scope viewing it is relevant to evaluate the results of the present experiment in terms of specific, selected values of target detection time. For example, in order not to exceed a detection time of 20 seconds after adaptation to a luminance of 3100 millilamberts, it is necessary that target luminance be above a certain minimum value for any given light adaptation duration. Consider the data of JB at a background luminance of -0.22 log millilamberts in Figure 4. After only a few seconds of light adaptation, target luminance may be as low as 0.14 log millilamberts. After about 25 seconds of light adaptation, target luminance must be increased to nearly 1.41 log millilamberts in order for the target to be detected within 20 seconds after the termination of light adaptation. After about 50 seconds of light adaptation, a target luminance higher than 1.64 log millilamberts is required for detection within 20 seconds.

Similar analyses can be made in terms of changes in background luminance necessary to compensate for changes in adaptation duration from the data of Figure 6. It is apparent that increased duration of light adaptation can only be compensated for by reducing background luminance when a detection time of relatively long duration is selected as the criterion. Even at the highest target luminance employed, for example, detection time can never be reduced below about 25 to 35 seconds by decrease in background luminance after 120 seconds of light adaptation.

The relation between target luminance and background luminance for a given visual effect, e.g., a detection time of ten seconds following a specific condition of light adaptation, could be determined from the data of the present experiment by graphical interpolation. The variability of the results is such that this sort of analysis is probably not warranted.

However, it appears that in the range of luminances investigated, a given increase in log target luminance is offset by an increase in log background luminance approximately four times as great. Practically, this means that the effect of a given change in target luminance on visibility is much greater than a comparable change in background luminance.

It is not uncommon to find the results of discrimination experiments presented in terms of contrast, where contrast is defined as the ratio of a luminance increment or difference to the adapting or background luminance. This practice may be traced to experiments which were designed to test the constancy of the Weber fraction. For the description of a stimulus presentation, however, the specification of contrast alone is inadequate. Either target or background luminance must be specified in addition to contrast for a complete description. If contrast values had any generality of meaning independent of the specific luminance values for which they were calculated, all of the curves of Figure 7 would be superimposed. This would be the case only if target luminance and background luminance were directly proportional for a given visual effect.

SUMMARY

1. Time required for the detection of a target "pip" on a simulated PPI scope presentation was determined after five durations of adaptation to a luminance of 3100 millilamberts. Various levels of maximum target luminance was employed at each of four values of maximum background luminance.

2. Target detection time increases with increase in the duration of light adaptation up to a maximum value which depends on the target and background luminance levels. The maximum value is reached after approximately the same light adaptation duration for all values of target and background luminance.

3. For a given background luminance and constant duration of light adaptation, an increase in target luminance results in a decrease in detection time down to a limiting minimum value.

4. For a given target luminance and light adaptation duration, an increase in background luminance results in an initial gradual increase in detection time, followed by a rapid increase in detection time as the value of background luminance nears that of target luminance.

5. Detection time may be expressed as a function of contrast between target and background for selected constant values of target or background luminance. The exact form of this relation depends on the value of target or background luminance for which the relation is determined.

6. Relations among target luminance, background luminance, and light adaptation duration for constant detection time are discussed briefly.

BIBLIOGRAPHY

1. Blackwell, H. R. Contrast Thresholds of the Human Eye. Journal of the Optical Society of America, Volume 36, 1946, pp. 624-643.

2. Craik, K. J. W. The Effect of Adaptation on Differential Brightness Discrimination. Journal of Physiology, Volume 92, 1938, pp. 406-421.

3. Haig, C. The Course of Rod Dark Adaptation as Influenced by the Intensity and Duration of Pre-adaptation. Journal of General Physiology, Volume 24, 1941, pp. 735-751.

4. Hanes, R. M. and Williams, S. B. Visibility on Cathode-Ray Tube Screens: The Effects of Light Adaptation. Journal of the Optical Society of America, Volume 38, 1948, pp. 363-377.

5. Hecht, S. Rods, Cones, and the Chemical Basis of Vision. Physiological Review, Volume 17, 1937, pp. 239-290.

6. Hecht, S., Haig, C., and Chase, A. The Influence of Light Adaptation on Subsequent Dark Adaptation of the Eye. Journal of General Physiology, Volume 20, 1937, pp. 831-850.

7. Mote, F. A. and Riopelle, A. J. The Effect of Varying the Intensity and Duration of Preexposure upon Foveal Dark Adaptation in the Human Eye. Journal of General Physiology, Volume 34, 1951, pp. 657-674.

8. Simonson, E., Blankstein, S. S., and Carey, E. J. The Relationship between Light Adaptation and Dark Adaptation and its Significance for Appraisal of the Glare Effect of Different Illuminants. American Journal of Ophthalmology, Volume 29, 1946, pp. 328-340.

9. Soller, T., Starr, M. A., and Valley, G. E. Jr. Cathode Ray Tube Displays. First Edition. McGraw-Hill Book Company, Inc., New York, 1948, p. 650.

10. Wald, G., and Clark, A. B. Visual Adaptation and Chemistry of the Rods. Journal of General Physiology, Volume 21, 1937, pp. 93-105.

11. Williams, S. B. and Bartlett, N. R. Visibility on Cathode-Ray Tube Screens: Problems and Methods. Journal of Psychology, Volume 25, 1948, pp. 401-417.